

# Effect of the Environment on the Fundamental Plane of Elliptical Galaxies

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We present an analysis of interacting E/S0 galaxies location on the Fundamental Plane. Using the NEMO package, we performed N-body simulations of close encounters and mergers between two spherical galaxies. We followed how structural and dynamical parameters (central density, half-mass radius and velocity dispersion) of galaxies are changed during the encounter. We analysed the dependence of these changes on initial mass concentration and presence of dark halo. The results of our simulations are used to discuss the Fundamental Plane for interacting early-type galaxies.

## 1 Fundamental Plane

The Fundamental Plane (FP) defines one of the most important relationship for early-type galaxies. The FP combines surface photometry parameters ( $R_e$  – effective radius and  $\mu_e$  – effective surface brightness or  $\langle\mu\rangle_e$  – mean surface brightness within  $R_e$ ) with spectroscopy characteristics (line-of-sight central velocity dispersion  $\sigma_0$ ). The measured values of  $R_e$ ,  $\mu_e$  and  $\sigma_0$  for a sample of E and S0 galaxies do not fill this 3-parameter space entirely but rather a thin plane within it (with scatter  $\sim 0.1$  dex). The FP can be projected onto any two axes. Examples of these projections are the Kormendy relationship ( $\mu_e$ – $\log R_e$ ), and the Faber-Jackson relationship between luminosity and velocity dispersion.

The interpretation of the FP is still a matter of discussion. The most popular point of view is that the FP is simply a consequence of the Virial theorem and the fact that E/S0 galaxies have similar mass-to-luminosity ratios and homologous structure at a given luminosity.

The FP have several important implications. For instance, it can be used to study the evolution of galaxies as a function of redshift; the FP is a powerful tool for deriving redshift independent distance estimates; etc.

There are no *clear* evidences that either the slope, zero-point or scatter of the FP are dependent on spatial environment (see discussion in Pahre et al., AJ 116, 1606, 1998). The purpose of the present note is to explore possible influence of *strong encounters* of early-type galaxies on their general characteristics and on the location within the FP.

## 2 Fundamental Plane for Interacting and Merging Galaxies

In order to study the FP for intensively interacting early-type galaxies we have considered several pieces of observational data.

Fig.1 presents the Faber-Jackson relation for E/S0 galaxies belonging to 1) VV or Arp systems (28 galaxies, stars), 2) CPG or TURNER binary systems, and 3) Hickson compact groups (circles) according to the Hypercat Database (Prugniel & Maubon, astro-ph/9909482).

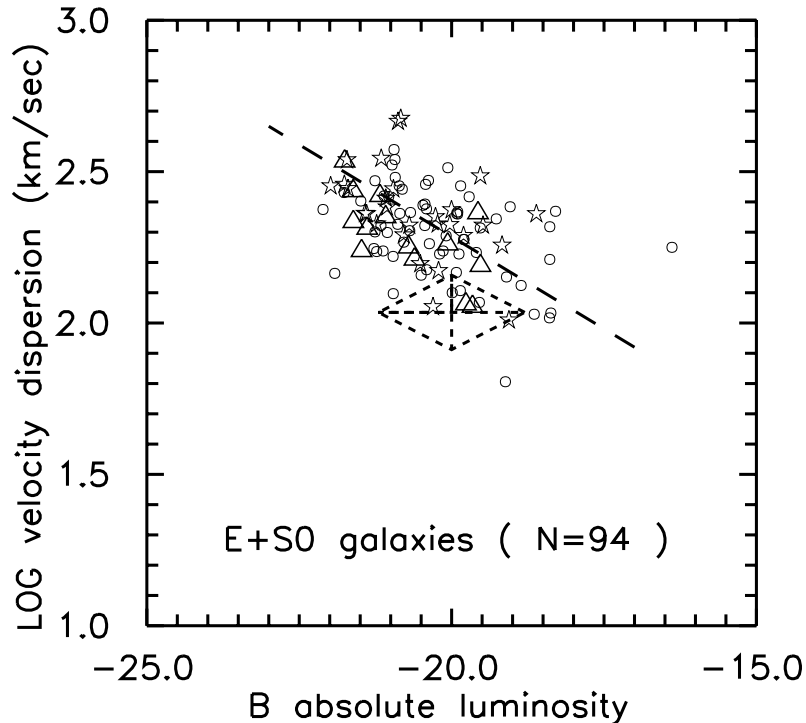


Figure 1: The Faber-Jackson relation for 94 interacting E/S0 galaxies.

Dashed line in Fig.1 shows the mean relation for 594 E/S0 galaxies according to McElroy, ApJS 100, 105, 1995:  $L_B \propto \sigma_0^{3.3}$ . The slope and the scatter ( $\sigma(\lg \sigma_0) = 0.15$ ) of the data for interacting galaxies are the same as for normal E/S0.

Triangles in Fig.1 present the characteristics of 14 remnants of disk-disk mergers (Keel & Wu, AJ 110, 129, 1995). As one can see, the mergers follow the same relation as early-type galaxies but with small shift ( $\sim 0.^m6$ ) to brighter absolute luminosities. The dashed rhomb shows the mean value ( $\pm 1\sigma$ ) for 9 starbursting infrared-luminous galaxies (Shier & Fischer, ApJ 497, 163, 1998). All these galaxies are in some stage of merging. Starbursting mergers demonstrate significant brightening ( $\sim 2^m$ ) in comparison with normal galaxies. One can expect that relics of disk-disk mergers and infrared-luminous mergers will evolve into normal ellipticals at the FP.

Fig.2 compares the FP location of ellipticals/lenticulars belonging to VV and Arp systems (crosses) with

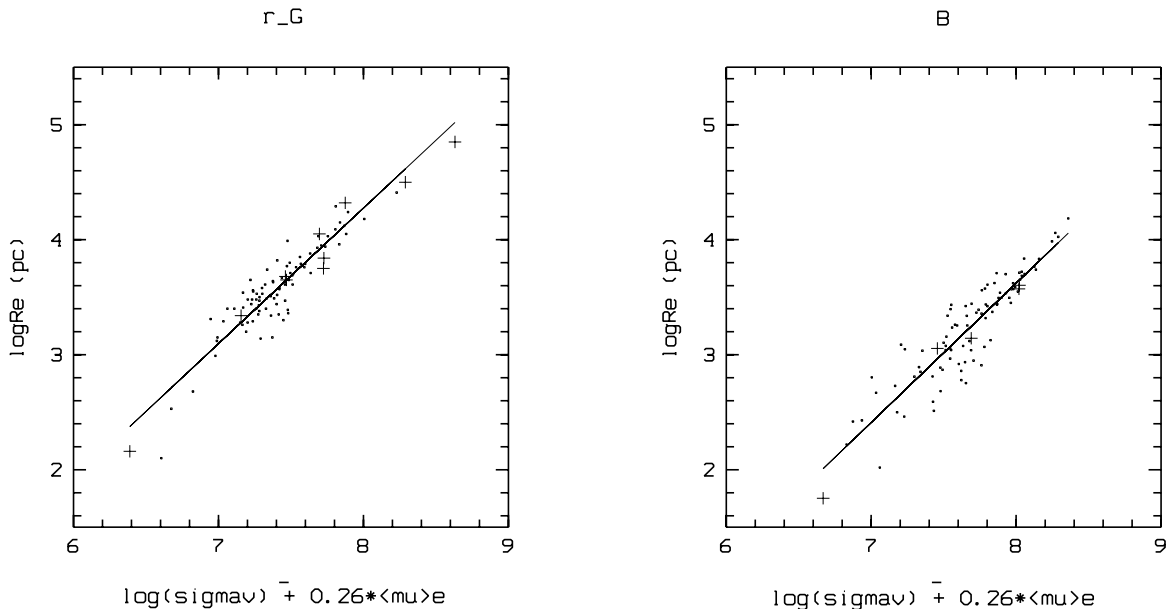


Figure 2: The FP for interacting E/S0 galaxies.

relatively isolated galaxies (points) (the data in the  $r_G$  passband are from Djorgovski & Davies, ApJ 313, 59, 1987; in the  $B$  filter – Bender et al., ApJ 399, 462, 1992). The FP scatter for interacting galaxies is the same (or even smaller) as for non-interacting objects.

One can conclude that present observational data about the global characteristics of strongly interacting E/S0 galaxies show that the environment has no or almost negligible effect on the FP. The only difference we see for forming (or young) ellipticals – they are significantly brighter (for fixed  $\sigma_0$ ) due to superimposed burst of star formation.

### 3 Numerical Modeling of Interacting Ellipticals

In order to check our empirical findings we have performed numerical modeling of close encounters of two ellipticals.

We simulated the evolution of the self-gravitating spherical galaxies by using the NEMO package (Teuben, PASP Conf. Ser. 77, 398, 1995). This is a freeware package designed to numerically solve gravitational N-body problems. It consists of subroutines for specifying initial configurations of stellar–dynamical systems (including many standard models) and subroutines for simulating the evolution of these systems based on various numerical schemes. In our computations, we used the scheme for constructing an ”hierarchical tree” (Barnes & Hut, Nature 324, 446, 1986).

We considered two models for encountering galaxies. One of them is Plummer’s spherically-symmetric model

$$\Phi(r) = -\frac{GM}{(r^2 + a^2)^{1/2}},$$

$$\rho(r) = \frac{3M}{4\pi} \frac{a^2}{(r^2 + a^2)^{5/2}},$$

where  $M$  is the galaxy mass and  $a$  is a scale length.

In some experiments galaxies are modeled by potential-density pair proposed by Hernquist for spherical galaxies (ApJ 356, 359, 1990)

$$\Phi(r) = -\frac{GM}{r+a},$$

$$\rho(r) = \frac{M}{2\pi a^3} \frac{a^4}{r(r+a)^3}.$$

It is well-known that both models are described by distribution function in analytical form and in the absence of numerical errors and dynamical instabilities remain time-stationary.

The number of particles used in our numerical simulations ranged from  $N = 20\,000$  to  $N = 50\,000$  per each galaxy. In this case, we managed to suppress substantially the effects of pair relaxation and to trace the evolution of merging galaxies on time scales up to  $t \approx 0.5 \times 10^9$  years.

We specified the initial distance between galaxies  $R = 37.3$  kpc and chose the initial relative velocity in the range  $V = 77.3 - 103.6$  km/s. As a result we have a close encounter with merging (the distance of the first closest approach was 5.2 kpc) and a distant encounter without merging (in this case the minimum galaxy separation was 10.3 kpc). Fig.3 presents some “snapshots” of a close encounter, showing the initial condition ( $t = 0$ ), the configuration near first maximum overlap ( $t = 30$ ), the configuration shortly before the final merger ( $t = 34$ ), and a merger state ( $t = 40$ ).

Results are presented in the following system of units: gravitational constant,  $G = 1$ , the galaxy mass,  $M = 1$ , the total energy of a sphere,  $E = -1/4$  (for Plummer’s sphere  $E = 3\pi GM^2/64a$ , for Hernquist’s sphere  $E = GM^2/12a$ ). Scaled to physical value appropriate for a typical elliptical galaxy, i.e.  $M = 10^{11} M_\odot$  and half-mass radius  $r_{1/2} = 3$  kpc ( $r_{1/2} \approx 1.31a$  - for Plummer’s sphere,  $r_{1/2} \approx 2.41a$  - for Hernquist’s sphere), units of distance, time and velocity are 3.73 kpc, 10.3 Myr,  $345.3 \text{ km s}^{-1}$ , respectively.

We followed the changes of central density, half-mass radius and central velocity dispersion ( $\sigma_0$ ). During the distant encounter all these parameters were not altered. As to the close encounter, in this case the most drastical changes in parameters were observed at the moment shortly before the final merger. It appears the range of parameter changes depends on initial mass concentration of a model (the Hernquist’s sphere is more concentrated than Plummer’s model). Amplitudes of relative changes of the parameters for two models are:

Plummer’s sphere –  $\delta r_{1/2} \approx 67\%$ ,  $\delta \sigma_0 \approx 17\%$ ,

Hernquist’s sphere –  $\delta r_{1/2} \approx 33\%$ ,  $\delta \sigma_0 \approx 6\%$ .

In some experiments we considered an encounter of two spherical galaxies with dark matter components. The effect of parameter changes was less pronounced than for the experiments without dark halo.

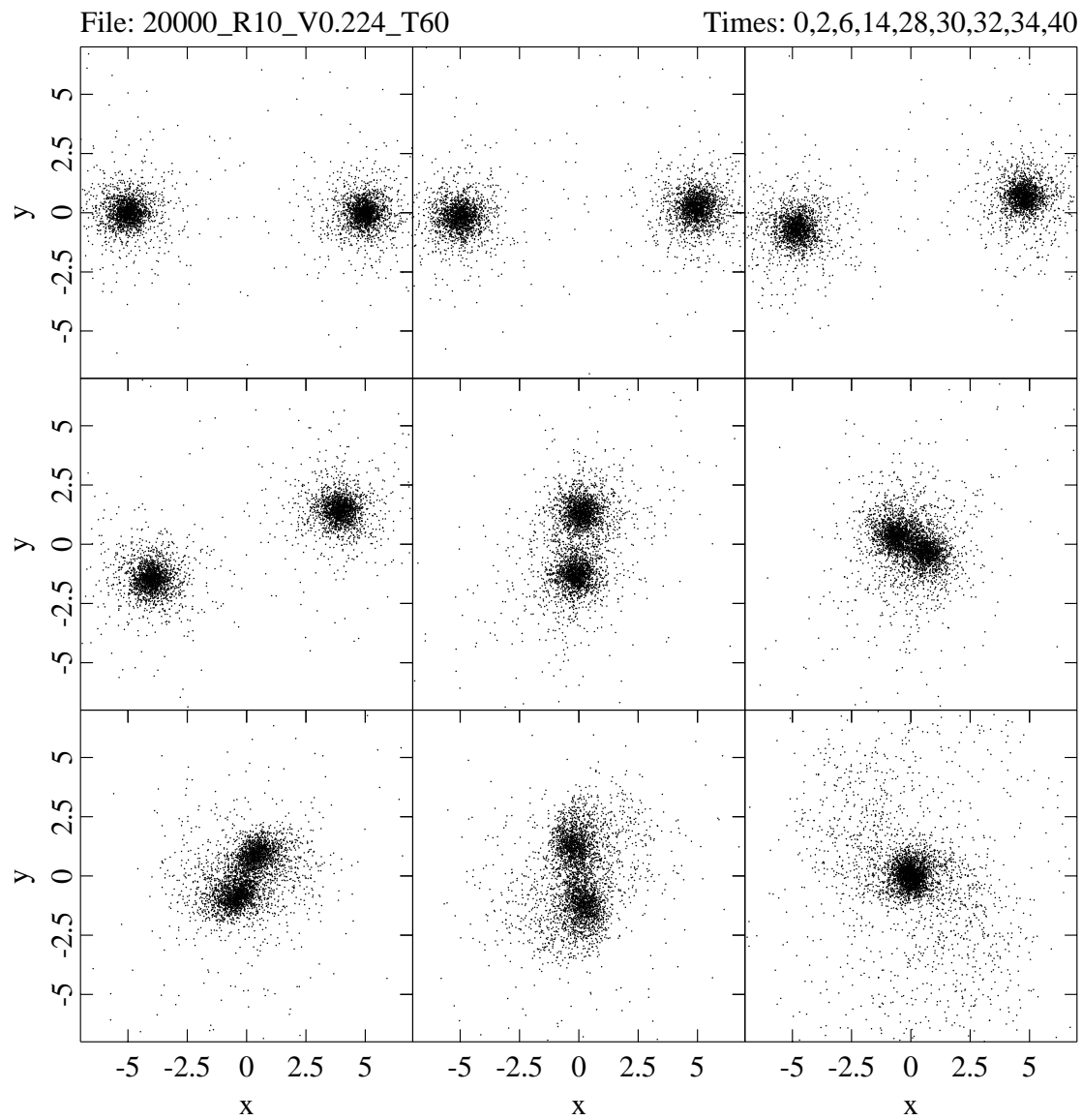
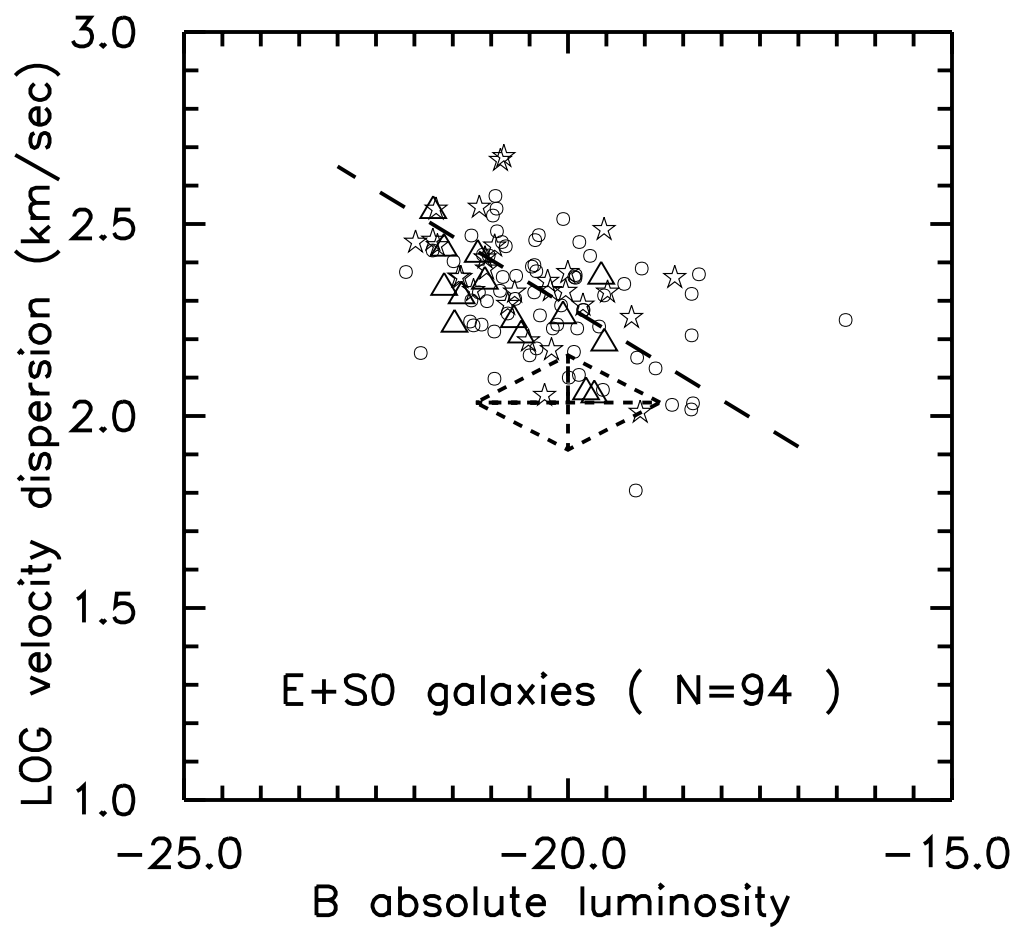


Figure 3: Close encounter of two identical Plummer’s spheres.

Our numerical experiments and observational data show that global parameters of early-type galaxies are quite stable to even strong gravitational perturbation. Close encounters between galaxies does change the FP parameters ( $R_e$ ,  $\mu_e$ ,  $\sigma_0$ ) within very limited time (a few  $\times 10^8$  years) before the final merger directly.



Wed Aug 11 12:06:31 1999

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